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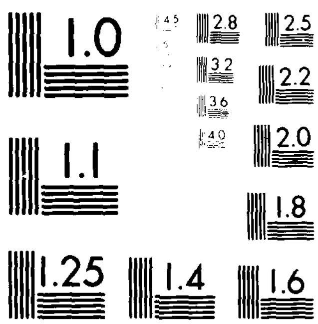


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# A Dual Task Analysis of Controlled and Automatic Detection

James E. Hoffman and Billie Nelson

Department of Psychology

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PLATO Project

Running Head: Controlled and Automatic Detection

Abstract

The secondary task methodology was used to measure the resource demands of controlled and automatic detection. Subjects were required to perform a secondary task of locating a flickering light together with a primary task of visual letter detection. Secondary task performance was lower when combined with the search task than in corresponding single channel control conditions. In addition, this decrement was approximately the same for both controlled and automatic detection. Similarly, both controlled and automatic detection latencies were increased in the presence of the secondary task and by the same amount. Controlled and automatic detection evidently share common resource demanding components.

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The secondary task methodology was used to measure the resource demands of controlled and automatic detection. Subjects were required to perform a secondary task of locating a flickering light together with a primary task of visual letter detection. Secondary task performance was lower when combined with the search task than in corresponding single channel control conditions. In addition, this decrement was approximately the same

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20. for both controlled and automatic detection. Similarly, both controlled and automatic detection latencies were increased in the presence of the secondary task and by the same amount. Controlled and automatic detection evidently share common resource demanding components.

This paper is concerned with the question of whether highly practiced and presumably automatic tasks can be performed in conjunction with other tasks without mutual interference. We will show that, at least for the case of automatic detection of letters, "automatic" processes may both provide and be subject to interference with other tasks.

## Automaticity in visual search

Visual search is a task for which the concepts of resources and automaticity are well defined. A variety of experiments initiated by Eriksen and Spencer (1969) and continued by Shiffrin and colleagues (Shiffrin and Gardner, 1972; Shiffrin and Grantham, 1974) indicate that the major limitation in performing simultaneous tasks is competition for "post- perceptual" decision, rehearsal, and response execution processes in short-term memory. In the case of visual search for a target letter in a display of letters, speed of search is limited by the rate at which subjects can compare encoded representations of the display letters to the target set in short-term memory. Schneider and Shiffrin (1977) showed that extensive practice in looking for the same set of characters (consistent mapping training) can result in search becoming "automatic." In automatic search, presentation of a target letter produces an automatic attention response in which the subject's attention is automatically drawn to the spatial position of the target. Depending on the task, an entire chain of processes may be initiated resulting finally in the production of an overt response. This sequence does not require active attention on the part of subjects for successful completion and indeed apparently cannot be inhibited.

This characterization of automatic detection suggests that its demands on short-term memory are minimal and therefore should provide little interference with other concurrent activities. Actually some interference can be expected due to the "automatic attention" response. For example, Schneider and Shiffrin (1977) showed that consistently mapped targets occurring in to-be-ignored display positions tended to disrupt the slow "controlled search" for other targets.

A somewhat different characterization of automatic search was provided by Hoffman (1978, 1979) in terms of a two-stage model of visual search. In the first stage, all of the display letters are encoded in a parallel, unlimited capacity system. This stage produces, in addition to encoded representations of the display letters, a rough index of the likelihood that each display letter is a member of the memory set. This index is used both to determine the order in which display letters are transferred to short-term memory for the serial comparison operation as well as providing a basis for making fast decisions. Consistent mapping training results in all of the decisions being based on the output of the initial, parallel stage.

This position differs from Schneider and Shiffrin's characterization of automatic search in two ways. First, it leaves open the possibility that the reading of information provided by the initial parallel stage is not automatic and may provide a basis of task interference for both controlled and automatic search. Second, it suggests that spatial allocation of attention does not occur in automatic detection.

## A dual task experiment

The question of whether automatic search utilizes resources might be answered through use of the secondary task methodology. In this case, the subject would be instructed to perform the primary task of visual search in conjunction with a secondary task. Performance on the secondary task presumably reflects the total resources that are not being used by the primary task.

Figure 1 shows the particular secondary task employed in this experiment. In single task conditions, the

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Insert Figure 1 About Here

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subject indicates whether or not a member of a predefined memory set is present in a visual display of letters. The subject's reaction time (RT) is the variable of interest. Letters are either consistently mapped (CM) or varied mapped (VM) which leads to automatic and controlled search respectively (Schneider and Shiffrin, 1977). Search is presumably automatic when RT is independent of memory set size and display size.

The other task (flicker location) requires the subject to indicate which of 8 points of light arranged around the inner perimeter of the letter display is briefly extinguished at the moment the letter display is presented. In dual task conditions this response is made after the letter detection response. Location accuracy is the variable of interest. This particular task was employed for several reasons. It appeared to be a relatively simple perceptual discrimination which would impose minimal demands on short-term memory capacity. It was also

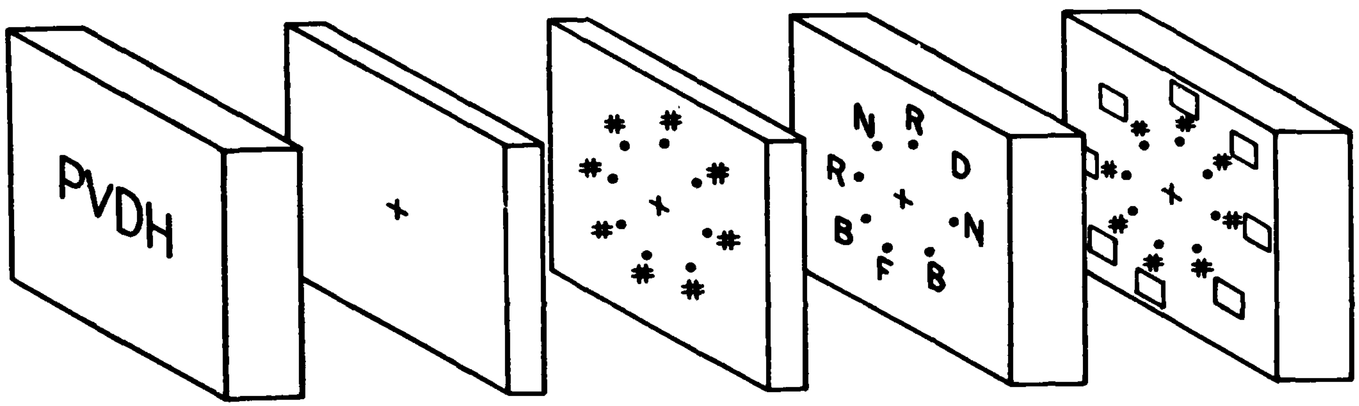


Figure 1: Sequence of events on each trial of the experiment. In dual channel conditions, subjects were required to indicate whether a member of the previously presented memory set (PVDH) was present in a circular display of letters. In addition, the subject was required to locate which of 8 points of light was briefly extinguished.

sufficiently dissimilar to the letter search task to be an unlikely source of "structural interference" (Kahneman, 1973). Finally it offered the possibility of providing an objective measure of the role of spatial attention in visual search. For example, if the letter target draws attention we might see superior detection of the flicker information when it is in close spatial proximity to the target letter. Similarly, if attention is allocated to the flicker position we should see fast detections of target letters adjacent to the flicker.

In summary, the resource demands of controlled and automatic search are to be measured in terms of performance of a secondary task of flicker detection. The role of spatial attention in these two search modes is to be measured in terms of dual task interactions when the flicker and target letter are in proximate spatial positions.

## Method

Subjects. Subjects were 14 males and 14 females with normal or corrected to normal vision.

Apparatus and Stimuli. Presentation of visual displays and timing was provided by a PLATO V terminal which has a plasma panel screen. Timing was provided by the terminals microprocessor and had a period of approximately 7 msec. Letters and masks were .3 x .23$^{\circ}$ of visual angle in height and width respectively and were defined on a 9 x 7 dot matrix. Letters appeared in a circular display with a diameter of 4.5$^{\circ}$ of visual angle. The dot used for the flicker task subtended .07$^{\circ}$ of visual angle. Subjects responded by pressing keys on a typewriter style keyboard.

Procedure. Each subject served in 10 sessions, each consisting of 9 blocks of trials. Each pair of sessions represented a complete replication of the experiment: 2 memory set sizes (1 or 4) x 2 display set sizes (2 or 8) x 2 mapping conditions (consistent or varied mapping) x single/dual channel. In addition, each session contained a single block devoted to performance of the flicker task alone.

Each block of trials consisted of 48 trials, half of them containing a target letter (a member of the memory set) and half containing only distractors. On each trial, the subject was presented with a memory set which remained on view until the subject initiated the trial sequence.

A fixation cross appeared in the center of the screen followed by a sequence of 3 arrays. A typical sequence is shown in Figure 1. A set of 8 premasks appeared for 250 msec. Next the premasks were replaced by the letter array with blank positions containing a $ symbol. This display remained on until the subject responded. Simultaneously with the onset of the letter array, one of the 8 light points was extinguished for 28 msec. and then illuminated again. In search only blocks, this flicker was to be ignored. In dual task conditions, the subject was to report which of the 8 light points had flickered. This report was made after the subject made his/her search task decision. At the end of each trial the subject received feedback concerning the accuracy of response on each task and the latency of the search task response.

The subject initiated each trial with his/her left hand and responded yes/no as to the presence or absence of a memory set letter in the display by pressing one of two keys with the right hand. In flicker only blocks, the subject was still required to execute a motor response with the right hand but this response was unrelated to the stimulus. In these blocks the entire display consisted of the symbol "$".

In consistent mapping (CM), the memory set letters were always taken from the set G, C, O, S and distractors from the set L, T, X, M. In varied mapping (VM), memory set elements were taken either from the set R, E, N, F or P, V, D, H with the distractors chosen from the alternate set. Each VM set was used equally often as target or distractor sets in each block in a random order.

The assignment of letters to positions in the display was random. After assignment of a target letter to a display position, on target-present trials the flicker location was determined according to the following schedule. There were 5 flicker-target "distances". A distance of 0 corresponds to the flicker occurring adjacent to the target while a distance of one corresponds to the flicker being one position removed from the target letter (either clockwise or counterclockwise) and so on. Each of these 5 distances occurred equally often in each condition. Notice that this procedure introduces a small statistical dependency between the locations of the flicker and target letter.

The order of blocks within a session was random within the constraint that each block occur in each presentation position equally often. In addition, each subject received the identical order of the blocks across sessions.

Subjects were instructed to treat the letter search task as primary and the flicker task as secondary.

## Results

Flicker Location Accuracy. Recall that performance on the secondary task of flicker location was presumed to reflect the resource demands of controlled and automatic search tasks. Figure 2 shows percent correct flicker location as a function of memory set size and display set size for both CM and VM search.

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Insert Figure 2 About Here

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These data make it quite clear that both kinds of search compete for a resource required in localizing the flicker. In addition, the difficulty of the search task, as indexed by the product of memory set size and display set size, influenced flicker location performance. The highest load (memory set = 4, display set = 8) caused a small drop in performance relative to the other load conditions. Surprisingly, this effect of load is present even for CM search which actually produces slightly more interference than VM search. Given that secondary task performance is a measure of the resources utilized by the search task, we conclude that both automatic and controlled search require use of some limited resource and to approximately the same extent. This resource competition is more severe when the number of comparisons required for the search task is increased. This load effect occurs only for very high loads and is small compared to the overall decrement that results from simply combining the two tasks.

A repeated measure analysis of variance of these data revealed a significant effect of consistent vs. varied mapping ($F(1,24)=5.9$, $p<.05$) as well as the interaction of memory set size and display set size ($F(1,24)=8.6$) .

Search Reaction Time. The average correct reaction time for the search task as a function of processing load, varied vs. consistent mapping, single vs. dual channel, and response type (positive or target present vs. negative or target absent) is

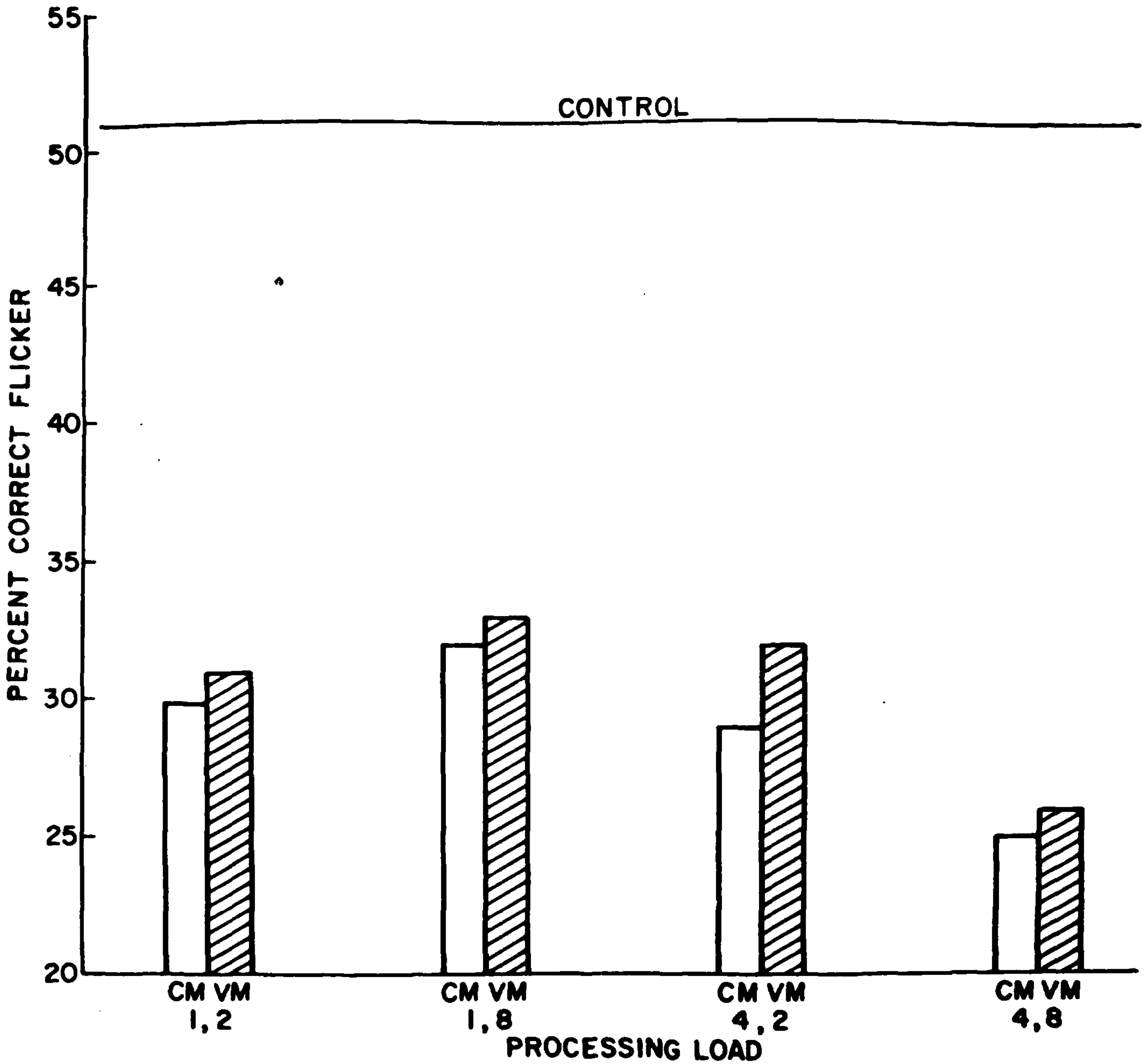


Figure 2: Percent correct flicker as a functionof load in search tasks. First (second) number is the number of letters in the memory (display) set. Control performance represents flicker location in single channel conditions.

shown in Figure 3. Consider first the single channel performance

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Insert Figure 3 About Here

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represented by the solid lines. The logarithmic scale used for processing load disguises the linear relation between RT and processing load for VM search. The slope for positive data was 27.2 msec. ($r^2$=.96) and of that the negative data 47.0 msec. ($r^2$=.98). In contrast, RT for CM search was relatively independent of load for both positive and negative responses.

An additional finding, not apparent in this figure, concerns the load=8 condition. RTs here can be separated into two types: M=1, D=8, and M=4, D=2. Despite the fact that these two conditions have similar processing loads, in terms of the product of memory set size and display set size, they produce quite different performance. The M=4, D=2 condition was 95 msec. slower than the M=1, D=8 condition for VM search. This held true even for the CM condition which showed an effect of 123 msec. Except for the latter finding concerning CM search, these results replicate the findings of Schneider and Shiffrin (1977).

The slower search RT in the M=4, D=2 condition relative to the M=1, D=8 condition for CM search is probably due to confusability effets. In the D=2 condition, six of the display positions contained the symbol "$" which was physically similar to one of the CM memory set items (S). With a memory set of 4 there was greater confusability between the memory set and display characters. It should be noted that this effect was present even for the last session pair and was still sizable (80 msec).

This effect, if it can be replicated in other types of CM search, is of potential importance in understanding the nature of automatic detection. For example, suppose that automaticity was obtained by "unitizing" the individual memory set elements into a higher order structure. If the subject based his/her decision on the activity in this structure for all memory set sizes, then search RT would be independent of memory set size. This model would predict that M=1, D=2 and M=4, D=2 conditions would produce equivalent search latencies which they do not (481 vs. 562 msec. for the last session pair). This suggests that in CM search the subject is not using the same memory set information independent of memory set size. Smaller memory sets allow the subject to reduce confusability between memory set items and display items that is present for larger sets.

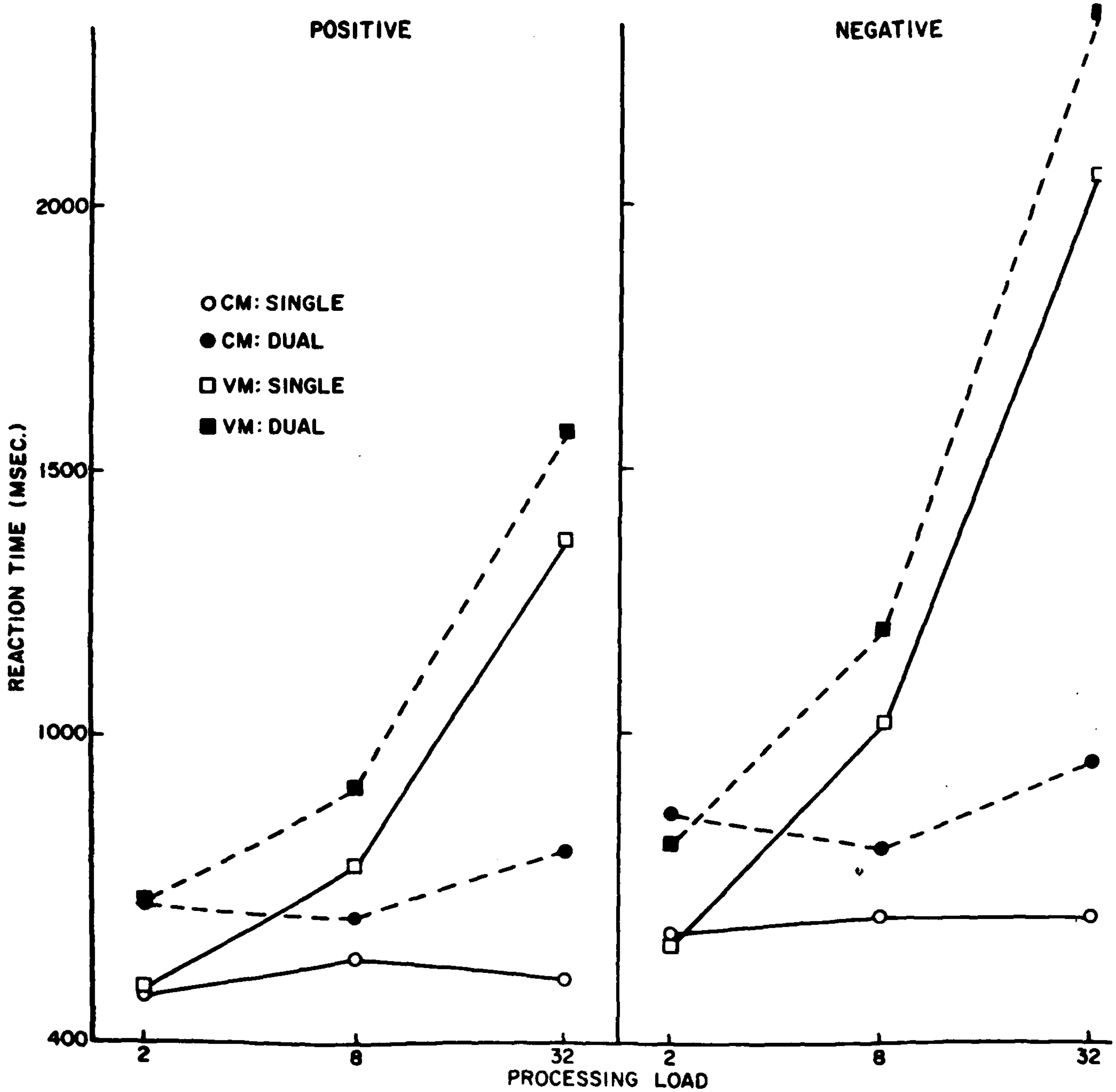


Figure 3: Average correct reaction time as a function of processing load (memory set size x display set size). Solid (dashed) lines show single (dual) channel performance.

Dual Task reaction times: Figure 3 shows that the search RT was increased when subjects had to perform the flicker location task in addition to the letter search task. This effect is largely additive with respect to the mapping, load, and response type of the search task suggesting that the addition of a secondary task added a constant time to the search process. There is however, a small but significant interaction between search load and single vs. dual task conditions. For example, in VM search the RT difference between load=1 and load=32 is 1160 msec. for the single channel condition and 1241 msec. for dual channel conditions. The corresponding values for CM search are 30 and 100 msec.

A repeated measures analysis of variance on these data revealed that the effect of single vs. dual channel was significant ($F(1,24)=37.9$, $p<.01$) and did not interact with whether search was CM or VM ($F(1,24)<1$). Single vs. dual channel did interact with processing load ($F(1,24)=16.5$, $p<.01$) and to about the same extent for CM and VM search ($F(1,24)=3.0$, $p>.05$).

Practice effects. Figure 4 shows how dual task performance changed with training. The top two panels show how the slope of the

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Insert Figure 4 About Here

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RT vs. load function (averaged across positive and negative responses) varied across sessions. Notice that CM search latency was almost immediately independent of load effects due to the low confusability between memory set and distractor items. Adding the secondary task initially induced a load effect but in the remaining sessions CM search remained relatively free of load effects.

VM search shows a remarkably stable slope across sessions confirming the results of Kristofferson (1972). Occasional small increases in slope can be observed in the dual task conditions relative to the single task condition.

The middle panel confirms the inferences drawn from Figure 3. The principle effect of adding the flicker location task is to add a constant to search RT reflected by an increase in the intercept of the RT vs. load function. This constant effect shows little sign of diminishing over sessions for either VM or CM search.

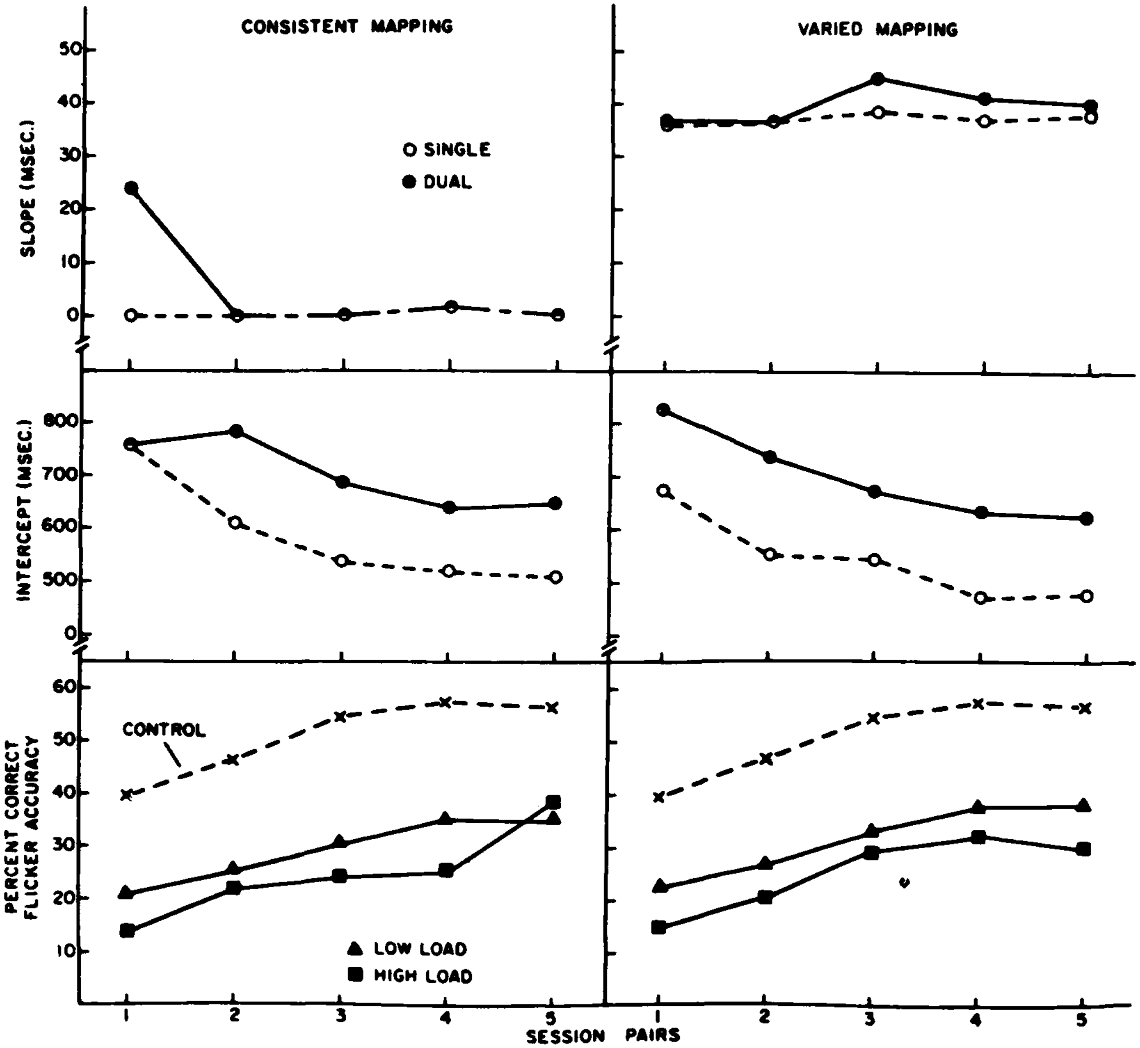


Figure 4: The effects of practice on search task slope intercept, and flicker location accuracy.

The bottom panel shows flicker location accuracy as a function of load over sessions. High load refers to the M=4, D=8 condition while low load is the average of performance on the remaining three load conditions. Once again it can be seen that secondary task performance reflected the load imposed in the search task. This load effect remained relatively constant over sessions for both CM and VM search. The exception is the last session pair in the CM condition in which the load effects are eliminated. This is surprising in view of the lack of load effects exhibited in terms of RT on the CM search task. However, the slope measure does obscure small load effects. Table 1 shows RT as a function of load for the last two

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Insert Table 1 About here

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session pairs in the CM condition. Notice that in the single channel condition there is a large decrease in the RT's in the M=4, D=8 condition as subjects move from session pair 4 to 5. This decrease in primary task load effects is faithfully reflected in the abolishment of the load effects on secondary task performance. Notice however that a large overall effect of dual channel condition remains in the CM RT's as well as the flicker location accuracy.

Spatial Adjacency effects. Table 2 shows the way in which correct search RT depended on distance from the flicker location for CM and VM search. For VM search. targets

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Insert Table 2 About Here

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were detected about 100 msec. faster when they occurred ajacent to the flicker (distance=0) relative to other positions. The time to detect the CM target was independent of distance from the flicker. This distance x mapping interaction was significant ($F(4,108)=3.0$, $p<.05$).

A similar pattern appears to hold for search accuracy. Table 3 shows the probability of a "hit" given that the

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Insert Table 3 About Here

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flicker location was correct. For VM search, subjects were significantly more likely to detect the target when it appeared adjacent to the flicker ($F(4,108)=3.5$, $p<.05$). For CM search, there is a suggestion of such an effect but it was not significant ($F(4,108)=1.99$, $p>.05$).

Table 4 shows that distance between the flicker and target

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Insert Table 4 About Here

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letter did influence flicker location accuracy. Flicker location was more accurate when adjacent to the target letter for VM($F(4,108)=10.1$, $p<.01$) and CM ($F(4,104)=6.7$, $p<.01$) search. Unfortunately this effect is almost surely due to a bias to guess the target letter location as the flicker location. This could be evaluated directly by examining the distribution of location responses on trials when the subject was incorrect. Unfortunately these data were not retained. However two findings suggest a guessing interpretation. The effect of location did not interact with load for VM search ($F(4,108)<1$) even though the average RT for the M=4, D=8 target- present condition was 1576 msec. This would be too late to affect the processing of the flicker information. Second, in subsequent work we have eliminated guessing effects and have not observed any effect of target letter-flicker distance on flicker accuracy.

_A two state attention model._ It would be useful to review the major effects of time-sharing visual search with a secondary task of flicker location. As a first approximation, the effect of adding the flicker task to the search task is to add a constant to both CM and VM search time. Similarly, the flicker task accuracy is reduced by a constant when combined with either CM or VM search. These effects can be accomodated by a simple two-state attention switching model. We assume that on each trial in dual channel conditions, with some probability p the subject ignores the flicker task and performs the search task with speed t. With probability 1-p, the subject performs the flicker task attaining the accuracy obtained in the flicker-only condition (c). Search is delayed by time $\Delta t$. This leads to the following expressions:

(1) $F=pg+(1-p)c$

(2) $\Delta t=(1-p)t$

where F is the observed flicker performance, g is the flicker guessing rate (.125) and $t_f$ is the time required to perform the flicker discrimination.

Solving expression 1 for p yields a value of .54. Substituting this value in expression 2 yields an estimate of $t_f$=398 msec.

This model although attractive in giving a simple account of the major features of the data faces two difficulties. First, the model suggests that subjects attempted the flicker task on 56% of the trials which seems high in light of the instructions to treat it as secondary. Second, this model suggests that fast RT's should be associated with low flicker accuracy. To evaluate this prediction we took the entire distribution of correct CM reaction times in dual task conditions for the last 2 session pairs and rank ordered them. This distribution was divided into quarters and the associated flicker accuracy computed for each interval. These data are shown in Table 5.

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Insert Table 5 About Here

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It is clear that there is no relation between speed of search and flicker accuracy which is directly contrary to the predictions of the model.

Although the two state switching model seems to be an unlikely explanation for our time-sharing data we might still retain some of its aspects. Many subjects commented that they first discriminated the flicker information and then began the letter task. The accuracy of the flicker information that is obtained and also the amount of delay imposed on the search task may be determined by the time the subject samples the flicker channel based on instructions regarding the relative emphases placed on the two tasks. This approach will be considered in the discussion.

## Disucssion

The purpose of the present experiment was to examine the resource demands of controlled and automatic search by pairing them with a secondary task of flicker location. There are three main findings which speak to the nature of resources used in these two search modes.

First, we found that there was mutual interference between flicker location accuracy and either controlled or automatic search. Flicker location accuracy was lower when combined with both search tasks relative to when it was the subjects only task. Similarly, search latency was increased relative to single task performance when combined with flicker location. This increase was approximately the same for both search modes and was virtually independent of search load.

Our second finding concerns the effects of confusability between memory set items and distractors in automatic search. We found that when the display contained distractors ($'s) which were highly similar to one of the letters in the CM memory set (S), RT was increased relative to a display containing non-confusable distractors. This effect of distractor confusability was greatly reduced when the subjects used smaller memory sets indicating that they had some control over the information used in the search decision.

Our third finding is that VM search accuracy and speed was improved when the target occurred near the location of the flicker. CM search latency and accuracy were relatively unaffected by the spatial proximity of flicker and target letter. These results suggest that spatial attention can improve performance in controlled processing but not automatic processing.

These results can be understood within a framework that offers a specific mechanism for producing load and confusability effects in recognition memory procedures similar to the search task utilized here. Ratcliff (1978) has recently introduced such a framework in the form of a resonance metaphor. Each of the elements in the memory set can be represented by a tuning fork. Presentation of a probe produces activity in each element in parallel. The degree of activity is a function of the similarity or relatedness between the probe and memory set element. The decision strategy is to say "yes" if activity in any tuning fork exceeds some positive criterion and respond "no" when activity in all forks reaches some negative criterion.

This model is embodied in a random walk process. The probe can be viewed as set of features. Each matching feature drives the random walk process toward a positive "absorbing barrier" while mismatching features drive the process toward a negative barrier. It is convenient to view the accumulation of these features as a serial process occurring over time. Thus if subjects can control the number of features to be sampled (or sampling time), they can improve their accuracy by extending the sampling time. This latter feature allows the model to account for speed-accuracy trade-off effects in reaction time.

Memory set size effects arise in this model because, on negative trials, RT is determined by the slowest comparison process. This value increases with increases in the number of comparisons. On positive trials, the match (or relatedness) between the probe and its corresponding memory set element declines with increasing memory set size. No specific mechanism is advanced for this latter effect; it might be that relatedness is partially determined by a serial rehersal of memory set information. This model has not yet been extended to the domain of visual search in which more than a single probe is presented. However it can be seen that at least qualitatively the model would predict an interaction between memory set size and display size. Increases in display size increase the number of potential features matching those in the memory set producing longer comparison times.

In this context, automatic search may occur when, through the process of training, the relatedness between memory set elements and distractors becomes very small. In such cases, increases in set size have virtually no effect on reaction time (Ratcliff, 1978).

Let us now consider how this model offers a perspective on the three findings outlined earlier.

Task interference occurs because the subject can only perform one discrimination at a time. In the present experiment, it is likely that subjects first performed the flicker task and then the letter search task. The information required for performance of the flicker task (onset and offset of light) is of the "transient" variety and is conducted along visual pathways faster than the "sustained" form information required for performance of the search task (Enroth-Cugell and Robson, 1966). We assume that the subject uses "time-controlled processing" to sample information for the flicker discrimination. That is, information is sampled for some criterial time and a decision is based on that accumulated information. This sampling time shows up in the search RT as a constant increment for both controlled and automatic processing. When flicker location is the only task to be performed the sampling time can be extended producing increases in accuracy. Thus the model predicts the pattern of task interference that was obtained.

This model also accounts in a straightforward way for the confusability effects found in CM search. Even through the filler character ($) received consistent mapping throughout the experiment, its high degree of similarity to the letter "S" produced long comparison times even at the end of training. When subjects used smaller memory sets, these long comparisons were excluded producing fast responses.

The observed spatial adjacency effects in VM search suggest that attention to the spatial position of the target can speed target detection. This is consistent with other experiments showing that targets are detected faster when attention is explicitly directed to their vacinity (Eriksen and Hoffman, 1972; Logan, 1978). An attentional mechanism may be added to the random walk model by assuming that attention to a position biases the order in which features enter the random walk discrimination process. In VM search, this bias produces faster and more accurate hits. In CM search, where few features are required to classify a letter as being positive or negative, this bias will be much less effective.

Our results show that the interference between the search and flicker tasks is largely additive with respect to all aspects of the search process (load, mapping, and response type). However small but significant effects of load could be seen superimposed on the main effect of task combination. Similar effects can be observed in Logan (1978,1979). Isreal, Chesney, Wickens and Donchin (1980) recently examined the magnitude of the P300 component of the human evoked potential as an index of attention. They found that the P300 elicited by tones to be counted was reduced in the presence of a concurrent tracking task but was relatively unaffected by the difficulty of the tracking task. There appeared to be a small effect of tracking difficulty on P300 amplitude but it was not significant.

Several different sets of results then agree in showing that tasks with apparently quite desparate resource requirements may interfere with each other. This pattern of interferences is largely additive with respect to the difficulty of the tasks. We interpret this additivity in terms of a "discrimination process" which can handle one task at a time. What then is the source of the interactions that have been observed? The interaction suggests some sharing of resources between tasks. Certainly one source of sharing in visual search tasks is a rehearsal process. Subjects engage in rehearsal of the memory set letters before and during the trial. These rehearsals effect the speed of the recognition process such that presentation of a probe in close temporal proximity to its corresponding rehearsal results in fast recognition decisions (Seamon, 1976; Seamon and Wright, 1976). It seems likely that the encoding of the flicker position caused an interruption of the rehearsal process. This loss of "priming" from the rehearsal process may be the reason for the small increases in the slope of the RT vs. load function observed in dual task conditions.

A similar explanation may underlie the small load effects seen in flicker accuracy. The rehearsal process required for the largest load conditions may have competed with the encoding of the flicker location accuracy. The elimination of load effects on flicker location seen in the last session pair for CM search may reflect the withdrawal of the rehearsal process with the development of automaticity.

Thus, the major way in which tasks compete may be through a process of "attention switching" in which a discrimination process can operate on but one task at a time. However, a small component of interference is due to "attention sharing" in which processes utilized by two tasks may overlap in time. These conclusions are similar to those reached by Sperling and Melchner (1978). They concluded that for the case of two concurrent visual search tasks both switching and sharing were utilized.

Conclusion. A secondary task experiment showed that both controlled and automatic search require a common mechanism. The pattern of interference between the search tasks and a secondary task of flicker location suggested that both search modes require the use of a discrimination mechanism which can operate on one task at a time.

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